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COMPARATIVE ANALYSIS FOR COEFFICIENT OF FRICTION OF LM 25 ALLOY AND LM 25 GRANITE COMPOSITE AT DIFFERENT SLIDING SPEEDS AND APPLIED PRESSURE

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ABSTRACT

In today's competitive world material researchers are based on cost-efficient, lightweight, performance efficient and environment-friendly replacements of traditional metals and their alloys. Most of the engineering applications have surface contact which is further accentuated by the presence of either sliding or rolling motion between the surfaces. Thus, the surface responses such as friction and wear have also become important design criteria. These properties are further enhanced in multiphase materials due to the presence of ceramic reinforcements. In this work, I have presented a comparative analysis for the coefficient of friction for LM25 alloy and it's composite with 10% by weight of granite at similar sliding speeds and applied pressures using a pin on disc test. The effect of different speeds and pressures on the presence of reinforcement has also been analyzed.

***KEYWORDS**: LM 25 Alloy, Composite, Sliding Speed, Applied Pressure & Friction*

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Original Article

INTRODUCTION

LM 25 is a cast alloy of aluminum with good wear and corrosion resistance. This alloy conforms to BS 1490:1988 LM25. Castings are standardized as cast (M) condition, the precipitation treated (TE) condition, the solution treated and stabilized (TB7) condition and the full heat treated (TF) condition [1]. Its potential uses are increased by its availability in four conditions of heat-treatment in both sand and chill castings. It has many applications in almost all types of mobility engineering, utilities, but is a preferred in water transport, due to the acidic nature of seawater. In automobiles, it is used for the wheels, cylinder blocks and heads, and other engine and body castings. Since it is a casting material it is abundantly utilized for fabricating intricate shapes. It is preferred for manufacturing torpedoes in defense and automobile applications as the cast alloy possesses due to its good strength and low weight properties. Since Aluminum is compatible with almost all the available ceramics/ natural minerals, it has gained popularity as the most preferred matrix material for fabricating metal matrix ceramic composites. The densities and moduli of elasticity of all aluminum alloys including castings are directly dependent upon the alloying content. Like most aluminum alloys the casting alloys also exhibit high strengths and high elongation even at sub-zero temperatures [2]. Ceramics like silicon carbide, alumina, zircon, granite, Titanium Oxide, sillimanite, corundum etc. are being extensively used for the fabrication of Aluminum Matrix Composites [AMCs].

Aluminum Matrix Composites are being extensively used in mobility engineering applications due to their good friction and wear properties as well as higher stiffness [2]. For example, in aeronautics, due to their high

specific stiffness and low coefficient of thermal expansion (CTE), AMCs fulfill the necessary requirements to produce lightweight and dimensionally stable structures. Thus, in aircraft, AMCs are used for manufacturing of tubular struts for a frame and rib truss members for the mid-fuselage section of the craft, as rotor blades due to increased creep resistance and as the landing gear drag link, etc. In automobile sector, AMCs are being used as cylinder linings, clutch linings, brakes, etc. The particle-reinforced Aluminium provide excellent specific strength and stiffness, excellent thermal and electrical properties, affordability, etc., thus making discontinuous AMCs suitable for a wide range of applications. The high structural efficiency and isotropic properties of discontinuously reinforced / particulate reinforced Aluminium provide a good match for the required multiaxial loading of truss nodes, where high loads are encountered. Another important design criteria for design engineers is the life cycle affordability of the multiphase materials, since poor casting conditions and inappropriate techniques may lead to the disintegration of the matrix and the reinforcement at even low applied pressures and speeds[9]. The other problem is the machinability of AMCs, since the ceramic reinforcement tends to reduce the ductility. The preferred methods for fabrication are stir casting, powder metallurgy, squeeze casting, etc. Since, most applications of AMCs require good wear properties with a low coefficient of friction, in this work, I have compared the coefficient of friction of LM25 alloy and it's composite with 10% by weight of granite at different sliding speeds and applied pressures. Aluminum readily oxidizes in air, thus, in the initial period of rubbing, the oxide film separates the two material surfaces and there is little or no true metallic contact. The oxide film has low shear strength [7] and easily detaches from the surface as the contact period progresses.

Friction is the force that occurs at the interface between two contacting surfaces and opposes the relative motion between those bodies [6]. This force acts tangential to the interface and is directed opposite to the motion of the surfaces. The magnitude of the friction force is measured in terms of Coefficient of friction. Mathematically, Coefficient of friction μ is the ratio of frictional force F and normal force N:

$$\boldsymbol{\mu = F/N} \tag{1}$$

A distinction is often made between the magnitude of friction that must be overcome to initiate sliding, represented by the coefficient of static frictionμs, and the part that must be overcome to maintain relative speed, defined by the dynamic or kinetic coefficient of friction μk. For contacting surfaces the design engineers strive to keep the coefficient of friction lower for good wear behavior. Thus, for surfaces in sliding contact, low coefficient of friction equates to low wear rate [4]. Since last two decades, material scientists are working to develop composites with the low coefficient of friction. Since friction is a dissipative process, interfacial adhesion takes place between the two bodies in contact. The mechanism of energy dissipation due to friction in sliding surfaces is a combination of adhesion and plastic deformation. Thus, the total coefficient of friction is a summation of the adhesion component and the deformation component for ductile materials (aluminum matrix) with an additional material property of fracture toughness to be added for brittle materials (granite composite). The kinetic or sliding coefficients of friction are used with relative motion between objects and Figure 1, gives a comparison of COFs for some common engineering materials sliding on steel.

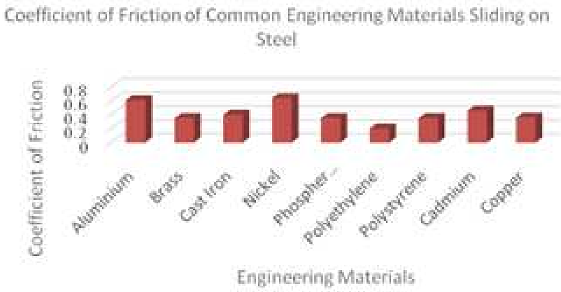

Figure 1: Comparison of COF for Common Engineering Materials

During the wear studies, the friction at the initial stage is low and remains at its start magnitude for some period of time. The factors responsible for this low value of friction are due to the presence of a layer of physisorped moisture, the oxide of metals and chemisorption of other elements in the surrounding, etc. It was observed by several authors that the variation of friction and wear rate depends on interfacial conditions such as normal load, geometry, relative surface motion, sliding speed, a surface roughness of the rubbing surfaces, and type of material, temperature, stick-slip, relative humidity, lubrication, and vibration. Among these factors sliding speed and normal load is the two major factors that play a significant role in the variation of friction and wear rate [8].

To combat the adverse effect of friction and wear various lubrication techniques are employed, using diverse lubricants such as hydrocarbons, ionic lubricants, inorganic solids etc. Lots of research is going on to develop advanced lubricants for aluminum and its alloys. For example, Jun Qu, Peter J Blau et el, in their work have discussed a significant reduction of 35% in friction and 55% in wear by using ammonium and imidazolium ionic lubricants with aluminum alloys in place of engine oil, [9].

MATERIAL PROPERTIES AND COMPOSITE FABRICATION

Aluminium-Silicon (Al-Si) alloys are the most important of the Al alloys, and are classified in three groups: hypoeutectic (<11 wt. (%) Si), eutectic (11-13 wt. (%) Si), and hypereutectic (>13 wt. (%) Si). The hypereutectic alloys are attractive to the automotive industry and desirable for wear resistant applications, where high strength and low weight ratio are required. The microstructures of the hypereutectic Al-Si alloys could be considered as metal-matrix composites (MMC) reinforced by hard particles [15]. The mechanical properties of Al-Si alloys depend on the microstructural parameters such as grain size, secondary dendrite arm spacing (SDAS), distribution of hard phases, the presence of secondary phases or Fe - intermetallic compounds, the morphology of Si particles (size, shape and distribution) and porosity. These are associated with the alloy composition, eutectic modification, and degassing and solidification rates. The matrix material used in the present investigation is Aluminium alloy (Si-7.2%), LM25, with the chemical composition (in weight percent) listed in Table 2.1. This alloy conforms to BS1490. This alloy is mainly used where good mechanical properties are required. It is, in practice, a general-purpose, high strength casting alloy. In its heat-treated form, its tensile strength can be increased from around 130-150 N/mm2 up to230-280 N/mm2. The performance of AMCs can be influenced by chemical reactions occurring between the aluminum and the reinforcing element. The friction load applied on the running surfaces can cause the break into parts of the hard, solid particles decreasing their reinforcing effect and increasing the wear rate [10]. The microstructure of LM 25 matrix and its 10 wt% granite composite is illustrated in Figure 1and 2. The alloy microstructure contains primary aluminum dendrites and eutectic silicon in the inter-dendritic region and around

the dendrites. Hypoeutectic Al-Si alloys have a microstructure of dendrites of Al-rich solid solution in a matrix of Al-Si eutectic which can vary in size from coarse to very fine. A minor impurity such as iron will form needles (β-intermetallics) which reduce the mechanical properties of hypoeutectic alloy. Thus, needle shape eutectic silicon and β intermetallic compounds are harmful for mechanical properties such as hardness and strength of the hypoeutectic Al-Si alloys [3].

Table 1: Chemical Composition of LM25 Alloy

Element	Si	Fe	Cu	Mn	Mg	Zn	Al
Wt%	7.2	0.2	0.23	0.1	0.4	0.1	90.87

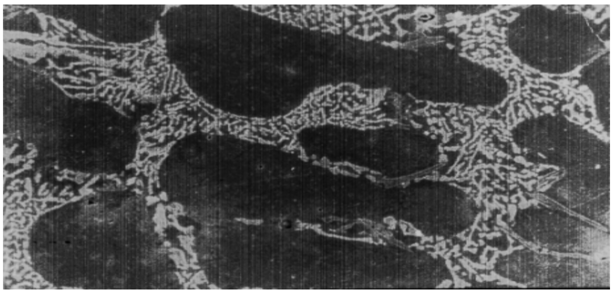

Figure 2: Magnified Microstructure of LM25 Alloy Showing Faceted Needle Shape Eutectic Silicon in the Inter Dendritic Region

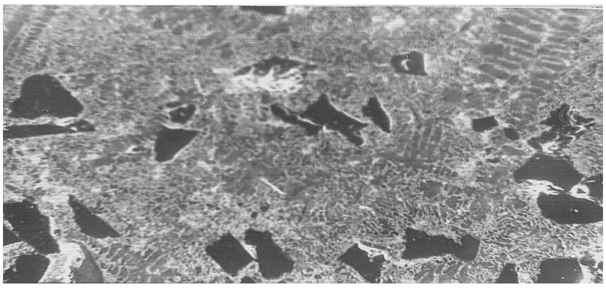

Figure 3: Microstructure of Composite Containing Granite Particles Showing Dendritic Type of Matrix Microstructure and Uniform Distribution of Particles

Natural Minerals granite was used as 10% by weight of reinforcement in LM 25 matrix. The coarse-grained igneous rock granite consists of quartz, feldspar and mica in shapeless interlocking grains, it is composed of at least 65% silica [4-5]. The mineral consists of a number of oxides in different fraction varying from source to source and hardness values lies between 6 –7 in Mohs scale. The physical properties used for identifying minerals are **cleavage** or **fracture**, **color**, **streak**, and **hardness.** Granite was obtained in the form of 1-5 Kg lumps and then crushed manually into small pieces with a mortar and pestle. The small pieces were crushed into powder in a ball mill to get particles of size range 50-150μm.

The LM 25 aluminum alloy ingot pieces were melted in a preheated graphite crucible in an induction furnace. The superheated molten metal was degassed at a temperature of 780°C by passing dry Nitrogen gas in the melt for 5 minutes. The reinforcing particles of granite were preheated to around800°C for 4 hours and then was added to the molten matrix alloy and stirred continuously by using a mechanical stirrer at 720°C. The stirring time was maintained between 5 – 8 minutes at an impeller speed of 600 rpm. During stirring, Magnesium (1Wt %) was added in small quantities to increase the wettability of the particulates. The melt temperature during mixing of reinforcing particles was maintained in the range

of 700°C-800°C. The dispersion of the preheated particulates was achieved in accordance with the vortex method. The mixture of melt and reinforced particulates was poured into the dried, coated, cylindrical permanent metallic molds of a size of the diameter of 10 mm and 130mm length. The molds were preheated to 200 °C, to remove moisture and gases, before pouring. The pouring temperature was maintained at 680°C. The melt was allowed to solidify in the molds, and after cooling the samples were taken for testing.

TESTING AND ANALYSIS

Two body sliding wear tests were carried out on both the prepared composite and LM 25alloy specimen. Pin-on-disc wear test machine (DUCOM, Bangalore, India Make, Model: TR-20 LE), Figure 4, was used for these tests. The tangential friction force and wear in microns were monitored with the help of electronic sensors. These two parameters were measured as a function of load, sliding velocity and percentage of reinforcement. For each type of material, tests were conducted at three different speeds (1.89,3.96 and 5.55 m/s). A cylindrical pin of size 10mm diameter and 130 mm length prepared from both the alloy and composite casting was loaded through a vertical specimen holder against the horizontal rotating EN32 disc of steel with hardness 65 HRC and diameter 50 mm. Before testing, the flat surface of the specimen was abraded by using 2000 grit paper. The tests were carried out at room temperature without lubrication for about 2Hrs and 20 min. Temperature rise near the mating surface of the specimen was measured as a function of test duration using a ChromelAlumel thermocouple. The wear tests were conducted under an applied pressure of 0.2 MPa to 1.8 MPa, increasing in steps of two. A tangential force was monitored continuously. Frictional force along with wear was measured by the digital display of pin on disc machine tester. This machine also provides a study of friction and wear characteristics in sliding contact with desired conditions. Sliding takes place between the stationary pin and a rotating disc. Normal load, rotational speed and wear track diameter can be varied for suiting the test conditions [13]. Tangential frictional force, and wear were monitored with electronic sensors and displayed by the attached monitor.

Figure 4: Pin on Disc Wear Testing Machine

The coefficient of friction of the alloy and the composite containing granite particles is plotted as a function of test duration for different applied pressures and at varying sliding speeds in figures 5-7.

Figure 5, shows that for an applied pressure of 0.2MPa the coefficient of friction (COF) initially increases to a peak value of 0.6 for the alloy LM25 with a sudden drop after 12 minutes duration, followed by a gradual rise to peak value. The COF for the Granite Composite (GC) at the same applied pressure of 0.2 MPa rises to a peak of 0.77 at the mid of the test to gradual decline to 0.6 at the end of the test. Whereas, at a higher applied pressure of 0.4MPa the COF keeps varying between 0.4 -0.45 for the LM25 alloy specimen throughout the test duration. However, for the GC specimen at 0.4MPa there is a sudden decline in COF at the start of the test from 0.5 to 0.42 gradually stabilizing till the end of the test. As the pressure rises to 0.6MPathe alloy shows stable decline in COF from 0.45 to 0.38 resulting in Seizure(S) after test

duration of 30 minutes. Whereas, at the same pressure GC shows a gradual decline from 0.44 to 0.35 till the end of the test. However, it is interesting to note that at 1.6 MPa the GC shows minor the gradual variation between 0.28 – 0.3 till Seizure. Thus, it can be observed that the coefficient of friction increases with test duration for the granite composite. This is because with the increase in time the particle interaction causing abrasion increases. It is evident from the figure that the coefficient of friction does not follow any trend with the test duration. However, it should be noted that the coefficient of friction decreases in general with applied pressure irrespective of the material that is the alloy or the composite. It is also seen that at lower pressures there is a wide range of variation shown by the coefficient of friction. Whereas at intermediate pressures the coefficient of friction varies marginally with the test duration for both the alloy and the composite. However, at higher values of applied pressure, the coefficient of friction increases gradually with the test duration.

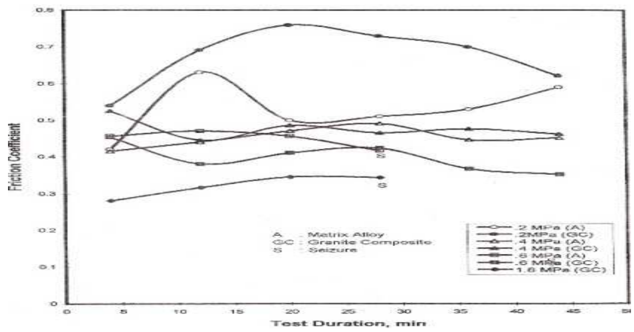

Figure 5: Comparison of the Test Duration versus Coefficient of Friction Plotted as Function of Sliding Speed 1.89 m/sec for Different Applied Pressures for Matrix Alloy and Granite Composite

Figure 6 illustrates the variation of the coefficient of friction at a speed of 3.96 m/sec. It is noted that the coefficient of friction decreases with the increase in applied pressure. It also demonstrates that the coefficient of friction at different test durations varies over a wider range of values at lower applied pressures. At a particular applied pressure, the coefficient of friction of the alloy is higher than that of the composite. The coefficient of friction of the composite at higher pressure increases slowly until the specimen seizes as is observed from the figures. As the alloy specimen seizes at the applied pressure either greater or equal to 0.4 MPa, the data for the coefficient of friction of alloy under higher applied pressures are obtained.

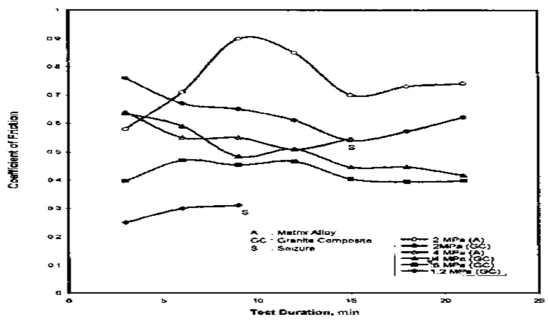

Figure 6: Comparison of Test Duration versus Coefficient of Friction Plotted as Function of Sliding Speed 3.96 m/sec for Different Applied Pressures for Matrix Alloy and Granite Composite

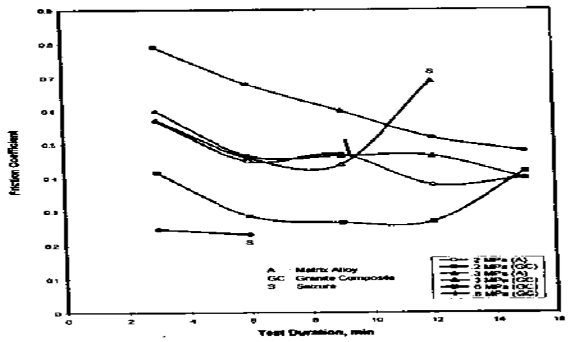

Figure 7: Comparison of Test Duration versus Coefficient of Friction Plotted as Function of Sliding Speed 5.5m/sec for Different Applied Pressures for Matrix Alloy and Granite Composite

Figure 7 gives the relation between the coefficient of friction of the materials at different applied pressures and at a fixed sliding speed of 5.55 m/sec as a function of test duration. It can be noticed that the coefficient of friction decreases with applied pressures for both the alloy and GC. It is also seen that before seizure the coefficient of friction of the alloy and composite decreases with the test duration. A coefficient of friction increases sharply for the base alloy at the applied pressure of 0.3 MPa just before the seizure.

Figure 8 depicts a relation between the coefficient of friction recorded as a function of applied pressure at different sliding speeds. As we know from the literature that the coefficient of friction as a function of sliding velocity generally has a negative slope and the slope is usually small, that is the coefficient of friction changes by only a few percents for a change in velocity of an order of magnitude. It is noted that the coefficient of friction decreases with applied pressure irrespective of the material except for the alloy at a speed of 5.55 m/sec. The Figure 8 shows that the low coefficient of friction results from increasing the load and sliding speed due to the change in shear rate. This event affects the mechanical properties of materials and in turn increases the destruction and wear of the surfaces, reduces the contact area, and breaks the oxide layer, thereby causing adhesion. It is also evident that the coefficient of friction for the composite decreases very sharply with the increasing applied pressure. Beyond a critical applied pressure the coefficient of friction reaches saturation. The critical pressure is varying with material as well as with the sliding speed. It is also evident that the coefficient of friction of the alloy is higher than that of the composite. The coefficient of friction for the granite composite at a speed of 1.89 m/s decreases with increase in applied pressure, showing almost a uniform variation till 1.6MPa. An almost similar trend is seen for GC at a speed of 3.96 m/s up to a pressure of about 1.2 MPa. However, for 5.5m/s there is a gradual decrease in COF with seizure at 0.6 MPa.

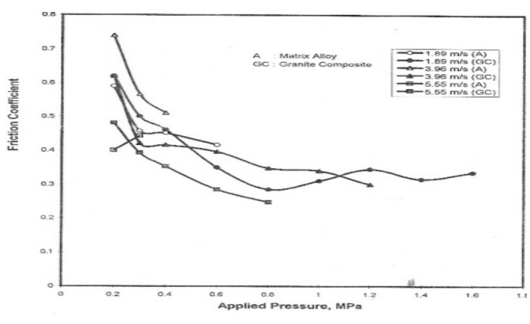

Figure 8: Friction Coefficient (at the End of the Test) Plotted as a Function of Applied Pressure for the Matrix LM25 and Granite Composite at Different Sliding Speeds

DISCUSSIONS &RESULTS

At each speed during the start of rubbing, the physisorbed and chemisorbed layers break up and clean surfaces come in contact which increases the bonding force between the contacting surfaces. The friction force also increases during this time due to the increase of ploughing effect of the inclusion of trapped wear particles This also results in an increase of surface temperature, viscous damping of the friction surface, increased adhesion due to micro-welding of the material, thus, leading to increase in coefficient of friction as well. After a certain duration of rubbing, the increase of roughness and other parameters attain a certain steady state value and hence the values of co-efficient of friction remain constant for the rest of the time.

The LM 25 alloy exhibits a higher coefficient of friction than that of the composite. This is primarily due to the fact that the hard dispersoids present in the composite surface act as protuberances which protect the matrix from the contact of the counter surface and results in the relatively less contact area between the surfaces. As a result the frictional forces as well as the coefficient of friction of the composite decreases as compared to the alloy. The presence of the reinforcing particles in the alloy improves the high temperature strength of the alloy, thus decreasing the degree of adhesion of the composite at a specific speed and applied pressure. This results in a low coefficient of friction. It is quite obvious from Figure 8 that the coefficient of friction is not following any particular trend with applied pressure and sliding distances. In case of granite composites, the coefficient of friction decreases with increase in applied pressure, irrespective of the sliding speed. This is because the contact area increases with increase in applied pressure, resulting in a high degree of frictional heating which in due course increases the flow ability of the matrix and the particulates. The higher degree of plasticity of matrix at high temperature tends to smoothen the surface. Thus, at elevated temperatures the surface roughness reduces for both the matrix and the composite, thus reducing the abrasive action, leading to lowering of the coefficient of friction, with an increase in applied pressure. However, for the alloy the coefficient of friction increases with the increase in applied pressure, Figure 7, unlike that observed at low speeds. This may be due to higher adhesive action of the alloy, with the counter surface under the combined action of the higher load and high sliding speed due to the high degree of adiabatic heating. On the other hand, at lower speeds, this adiabatic action is not so high due to plastic flow of the constituents, thus reducing the coefficient of friction at low applied pressures. The coefficient of friction decreases with test duration for low speeds of 1.89 m/sec and 3.96 m/sec, (Figure 5 –6), gradually stabilizing with time. At high speeds and applied loads the coefficient of friction of the composite increases at the last stage of the test, because of the adhesive action between the surfaces. Also for LM 25 there is an increase in the contact area due to the plastic yielding of the contract which is controlled by the combined effect of the normal and shear stresses. Also, according to Green (1955) [12], some of the strongly adhering contacts may also support tensile stresses and friction between unlubricated metals is due to shearing of junctions formed by adhesions between minute asperities on the sliding surfaces.

The fact that friction can vary not only as a function of time, but also from one place to another on the same surface at similar sliding times suggests that friction models that attempt to predict a single value of friction, and not a range or time-dependent distribution of friction values, may be overly simplistic [13]. As Rabinowicz[14] and others have discovered, the better lubricated the surface, the less likely it will be that large variations in friction will be observed, but in poorly lubricated or unlubricated tribo-systems, the spatial and temporal behavior of friction cannot be ignored in fundamental studies of friction processes because it reflects the complexities of asperity interactions, especially when lubricants are absent.

CONCLUSIONS

The composite exhibits a lower coefficient of friction than the matrix alloy. This is because the surface temperature of the granite composite is lower than that of the LM 25 alloy, however, with the increase in applied pressure the temperature rises. LM 25 being ductile in nature when it is in sliding contact with the abrasive plate, the coefficient of friction is high because of mechanical interlocking. It is also observed that the granite composite withstood much higher temperatures than the alloy before seizure. The presence of reinforcing granite particles tends to lower the coefficient of friction as compared to the alloy. The plastic flow along the sliding surfaces increases the real area of contact, causing an increase in space connections and increased friction force. The increase in surface temperature leads to gradual flattening of the protrusions, resulting in steady state and higher slide speed at high temperature, which reduce the shear force, reduce the coefficient of friction, and attain low roughness. As the load increases, frictional heat is generated at the contact surface, hence the decrease in the strength of materials. Thus the applied pressure and the sliding speed affect the amount of friction force. The wear rate significantly increases when the load increases, but the coefficient of friction decreases. On the other hand, small coefficient of friction values, together with an increase in sliding speed, loading, and sliding over long distances, reduce wear rate. Thus, maintaining appropriate sliding speed and applied pressure values can reduce frictional force and wear and thus improve the mechanical strength. Since the granite composite is harder, less plastic deformation and hence relatively less friction is experienced. It can be concluded thatLM25 granite composite can be used in applications where anti-wear properties are the main requirements of the design, like the teeth of the bucket of excavators, bearings, etc. It can easily be deduced that the coefficient of friction is highly influenced by load /pressure factor, sliding speed, and percentage of reinforcement. In addition, an the increase in load leads to a significant increase of the coefficient of friction. The values of friction coefficient decrease with the increase of sliding speed and applied pressure. The wear rates, on the other hand, increase with the increase of sliding speed and applied pressure.

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NOMENCLATURE

AMCs	Aluminium Matrix Composite
COF	Coefficient of Friction
CTE	Coefficient of Thermal Expansion
MPa	Mega Pascal
EN32	(080M15) Engineering Case Hardened Steel
Hrs	Hours
GC	Granite Composite
HRC	Rockwell Hardness of Scale C